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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Cloud and Pour Tests

Effects of Improper Carburetion

Flow of Oil through Bearings

PUBLISHED MONTHLY BY
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PETROLEUM AND ITS PRODUCTS

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Cloud and Pour Tests

THE cloud and pour points of oils are of importance where oils in storage or during use are exposed to cold conditions. Many oils which at ordinary temperatures are clear, transparent liquids, become, if the temperature falls sufficiently low, white, opaque, solid masses. In some cases either certain constituents of the oil are thrown down as precipitates as the temperatures become lower, or the whole mass of liquid solidifies at some particular temperature; in other cases as the temperature falls, the liquid becomes more and more viscous, and finally becomes a soft solid.

Much confusion has resulted in the past from the indiscriminate use of terms denoting this characteristic of oils, as well as from the variation in methods for its determination. For example, the term "cold test" varied according to whether it was regarded as the temperature at which solid matter commenced to separate, or the temperature at which an oil completely lost its fluidity. The "cold test" of low viscosity paraffin lubricating oils was considered to be the temperature at which the separation of solid paraffin wax was observed to commence; while the "cold test" of cylinder oils, black oils, and oils of naphthene base, which either deposit no paraffin wax or in which the separation cannot be seen, was considered to be that temperature at which they ceased to flow. Equally vague are the terms "freezing point," "melting point," "setting point," and "point of congelation."

A greater source of confusion than the loose use of descriptive terms has been the variation in methods of determination, and ignorance regarding the factors which influence the accurate determination of the "cloud point" or "pour point," particularly in the preparation of the sample for the test. The accepted meaning of these terms is clearly explained in the specifications considered later. The effect of cold upon lubricating oils is not the same as upon simple fluids such as water, alcohol, glycerine, benzene, etc. The latter have fixed and accurately ascertainable freezing points, at which a complete change from the liquid to the solid state takes place, but lubricating oils, which are mixtures of hydrocarbons of various melting points or freezing points, behave like solutions, and frequently deposit some portion of their constituents before the whole mixture solidifies. Interesting phenomena which can only be explained by changes in the inner or molecular structures, are observed in the pour test of many lubricating oils. If, for example, one takes the pour test of an oil without previous heating and then takes the pour test of the same oil after heating to 120° F. and after allowing the oil to cool to the same temperature as the first oil, the oil which has been heated solidifies at a significantly higher temperature, and the influence of the preheating seems to be effective for a considerable time, at least for 24 hours. Heating to temperatures below

90° F. apparently has no influence. Another factor which has an influence on the test is stirring the oil while cooling to determine the cloud point or pour point. In case an oil is stirred it solidifies at a lower temperature than when held stationary. This may be explained on the assumption that the movement of the oil destroys the formation of the fine network of microscopic particles of paraffin or asphaltic bodies which are separating out. This segregation gives the oil mass a certain support and thereby facilitates solidification. In an analogous way this explanation may apply to the influence of preheating; the waxy or asphaltic particles are probably transformed, by warming, into a very strongly dispersed state from which it is possible to form a finer and thicker network than in the oil which has not been heated.

Numerous tests have been devised to determine the cloud point and pour point of oil, each of which gives various and sundry results in the hands of different operators, due not only to ambiguity and lack of conciseness in the description of apparatus and method but also in the application of the methods to oils for which they are not suitable. Committee D-2 of the American Society for Testing Materials have taken considerable pains to work out a method for the determination of cloud point and pour point of lubricating oils. The method, while not new in principle, is more complete in detail than any previously published method. The method includes a precise definition of the cloud point and pour point, and classifies the oils to which each or both are applicable. Due consideration has also been given to the effect of previous treatment of the oil before the test is made. These tests, if made exactly as outlined, will give concordant results in the hands of different operators.

A. S. T. M. Tentative Method of Test for Cloud and Pour Points of Petroleum Products

Definitions

1. (*a*) The Cloud Point of a petroleum oil is that temperature at which paraffin wax or other solid substances begin to crystallize out or separate from solution when the oil is chilled under certain definite specified conditions.

(*b*) The Pour Point of a petroleum oil is the lowest temperature at which this oil will pour or flow when it is chilled without disturbance under certain definite specified conditions.

Scope

2. (*a*) The test for cloud point shall be used only for oils which are transparent in layers 1½ inches thick.

(*b*) The test for pour point shall be used for all other petroleum oils and may be used for oils on which the test for cloud point is permitted.

Apparatus (See Fig. 1)

Test Jar

3. The test jar, A, shall be of clear glass, cylindrical form, flat bottom, approximately

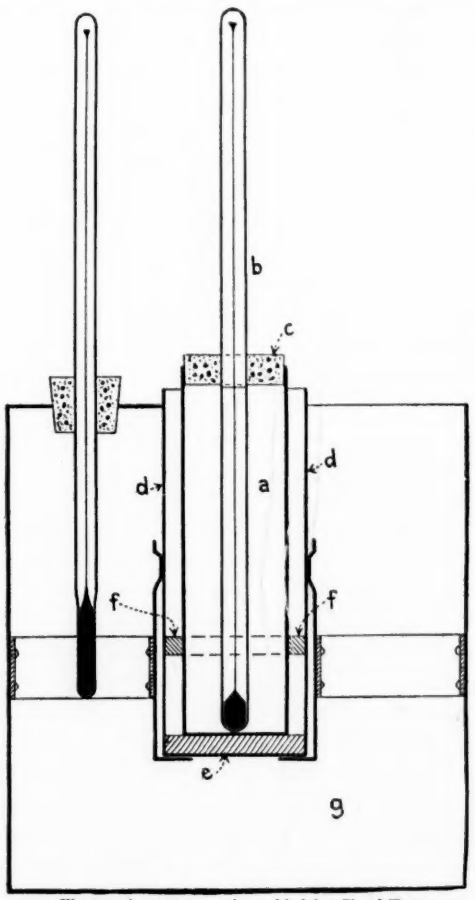


Fig. 1.—Apparatus as Assembled for Cloud Test

1¼ inches in inside diameter and 4½ to 5 inches high. An ordinary 4-ounce oil sample bottle may be used if the test jar is not available.

4 The thermometer, B, shall conform to the following specifications:

Type: Etched Stem Glass. Total Length: 222 mm.
Stem: Plain front, enamel back, suitable thermometer tubing; diameter 7 to 8 mm.
Bulb: Corning Normal. Jena 16 III, or equally suitable thermometric glass; maximum length, 9.5 mm.; diameter, not greater than stem.
Actuating Liquid: Mercury.
Range: —36° to +120° F.
Immersion: 4¼ inch. The words "4¼ inch immersion" etched on tube and also a line around the stem to indicate the depth of immersion.
Distance to —36° mark from bottom of stem: 120 to 130 mm.
Distance to +120° mark from top of stem: 19 to 25 mm.
Expansion chamber: To hold 212° F.
Filled: Nitrogen gas.
Top Finish: Plain.
Graduation: All lines, figures and letters clear cut and distinct. Scale graduated in 2° F. divisions. Scale numbered every 20° F., starting at —20° F., the —30° mark and each succeeding 10° line to be longer than the others.
Special Markings: "A. S. T. M. Cloud and Pour" serial number and manufacturer's name or trade mark etched on the stem.
Accuracy: Error at any point on scale shall not exceed one smallest scale division.
Points to be tested for certification: —28°, +32°, +92° F.

Cork

5. The cork, C, shall fit the test jar, and shall be bored centrally to take the test thermometer.

Jacket

6. The jacket, D, shall be of glass or metal, shall be water-tight, of cylindrical form, flat bottom, about 4½ inches deep, with inside diameter ½ inch greater than outside diameter of the test jar.

Cork Disk

7. A disk of cork or felt, E, ¼ inch thick and of the same diameter as the inside of the jacket will be required.

Gasket

8. The ring gasket, F, shall be about $\frac{3}{16}$ inch thick, and made to fit snugly around the outside of the test jar and loosely inside the jacket. This gasket may be made of cork, felt or other suitable material, elastic enough to cling to the test jar and hard enough to hold its shape. The purpose of the ring gasket is to prevent the test jar from touching the jacket.

Bath

9. The cooling bath, G, shall be of a type suitable for obtaining the required temperatures. The size and shape of the bath are optional but a support, suitable for holding the jacket firmly in a vertical position, is essential. The required bath temperatures may be maintained by refrigeration if available, otherwise by suitable freezing mixtures.

NOTE: The freezing mixtures commonly used are as follows:

For temperatures down to
35° F., ice and water.
— 5° F., crushed ice and sodium chloride.
—25° F., crushed ice and calcium chloride.
—70° F., solid carbon dioxide and acetone.

The last named mixture may be made as follows: In a covered metal beaker chill a suitable amount of acetone to 10° F., or lower, by means of an ice-salt mixture. Invert a cylinder of liquid carbon dioxide and draw off carefully into a chamois skin bag the desired amount of carbon dioxide, which through rapid evaporation will quickly become solid. Then add to the chilled acetone enough of the solid carbon dioxide to give the desired temperature.

Procedure

Procedure for Cloud Point

10. The oil to be tested shall be brought to a temperature at least 25° F. above the approximate cloud point. Moisture, if present, shall be removed by any suitable method, as by filtration through dry filter paper until the oil is perfectly clear but such filtration shall be made at a temperature at least 25° F. above the approximate cloud point.

The clear oil shall be poured into the test jar, A, to a height of not less than 1 nor more than 1¼ inches. The test jar may be marked to indicate the proper level.

The test jar shall be tightly closed by the cork, C, carrying the test thermometer, B, in a vertical position in the center of the jar with the thermometer bulb resting on the bottom of the jar.

The disk, E, shall be placed in the bottom of the jacket, D, and the test jar with the ring gasket, F, 1 inch above the bottom shall be inserted into the jacket. The disk, jacket and inside of jacket shall be clean and dry.

The temperature of the cooling bath, G, shall be adjusted so that it is below the cloud point of the oil by not less than 15 nor more than 30° F. and this temperature shall be maintained throughout the test. The jacket, containing the test jar, shall be supported firmly in a vertical position in the cooling bath so that not more than 1 inch of the jacket projects out of the cooling medium.

At each test thermometer reading which is a multiple of 2° F. the test jar shall be removed from the jacket, quickly but without disturbing the oil, inspected for cloud and replaced in the jacket. This complete operation shall require not more than three seconds.

When the bottom of the oil has become opaque to a height of not less than $\frac{1}{8}$ nor more than $\frac{3}{16}$ inch, the reading of the test thermometer, corrected for error if necessary, shall be recorded as the cloud point. The required height of cloud is approximately at the middle of the thermometer bulb. The test jar may be marked to indicate the proper level.

Procedure for Pour Point

11. Oils having a viscosity greater than 600 seconds, Saybolt Universal at 100° F., shall be allowed to stand in the test jar at a temperature of 60 to 85° F. for at least five hours prior to making the test for pour point. A viscous oil which has been stored in a warm place is liable to show an abnormally low, fictitious pour point unless this precaution is observed. Oils having a viscosity not greater than 600 seconds, Saybolt Universal at 100° F., may be tested without such preliminary standing.

After preliminary standing, if necessary, the oil to be tested shall be brought to a temperature of 90° F., or to a temperature 15° F. higher than its pour point, if this pour point is above 75° F., and shall be poured into the test jar, A, to a height of not less than 2 nor more than $2\frac{1}{4}$ inches. The jar may be marked to indicate the proper level.

The test jar shall be tightly closed by the cork, C, carrying the test thermometer, B, in a vertical position in the center of the jar with the thermometer bulb immersed so that the beginning of the capillary shall be $\frac{1}{8}$ inch below the surface of the oil.

The disk, E, shall be placed in the bottom of the jacket, D, and the test jar, with the ring gasket, F, 1 inch above the bottom, shall be inserted into the jacket. The disk, gasket and inside of jacket shall be clean and dry.

The temperature of the cooling bath, G, shall be adjusted so that it is below the pour point of the oil by not less than 15 nor more than 30° F. and this temperature shall be maintained throughout the test. The jacket, containing the test jar, shall be supported firmly in a vertical position in the cooling bath so that not more than 1 inch of the jacket projects out of the cooling medium.

At each test thermometer reading which is a multiple of 5° F., the test jar shall be removed from the jacket carefully and shall be tilted just sufficiently to ascertain whether the oil around the thermometer remains liquid. As long as the oil around the thermometer flows when the jar is tilted slightly, the test jar shall be replaced in the jacket. The complete operation of removal and replacement shall require not more than three seconds. As soon as the oil around the thermometer does not flow when the jar is tilted slightly, the test jar shall be held in a horizontal position for exactly five seconds, and observed carefully. If the oil around the thermometer shows any movement under these conditions, the test jar shall be immediately replaced in the jacket and the same procedure shall be repeated at the next temperature reading 5° F. lower. As soon as a temperature is reached at which the oil around the thermometer shows no movement when the test jar is held in a horizontal position for exactly five seconds, the test shall be stopped.

The lowest reading of the test thermometer, corrected for error if necessary, at which the oil around the thermometer shows any movement when the test jar is held in a horizontal position for exactly five seconds, shall be recorded as the pour point.

Effects of Improper Carburetion

EXPERIMENTS by the Bureau of Mines* have shown that nearly one-quarter of all the gasoline used by motor vehicles is wasted. From the quantity of gasoline consumed by the American public last year, this amounts to over one billion gallons or approximately $300,000,000 in money paid by the consumers at the prevailing price of gasoline. The U. S. Geological Survey estimates that our petroleum resources will be exhausted during the present generation, and even though this may be a little pessimistic it is certain that this supply will be depleted some day not far distant, and the present appalling wastage of this precious natural resource is little less than a calamity. There are, unfortunately, many motor vehicle users who shrug their shoulders at this loss because "gas is cheap," but if they would look a little further to the probable price they will have to pay for gasoline when it becomes scarce, they might well give it careful attention.

In this article the experiments of the Bureau of Mines mentioned above will be reviewed, and an insight given as to the probable causes and remedies for this unfortunate condition, as well as to what becomes of the wasted fuel, and the connection between this wastage and repair bills.

Examination of Vehicles in Use

Last year the Bureau of Mines selected 101 vehicles at random from the streets of Pittsburgh, representing all general classes of pleasure cars and trucks, and made chemical analyses of the exhaust gases while idling and running at various speeds without changing the carburetor adjustments. Fig. 1 shows some of the results of these tests taken during both summer and winter weather, which by the way, show an inappreciable difference. Each point represents the reading from one vehicle. The relation between the percentage of carbon dioxide in the exhaust gas and the efficiency of combustion is quite evident, and offers a ready means for checking the carburetor setting of any fleet of vehicles where attention is given to fuel economy. It is interesting to see how

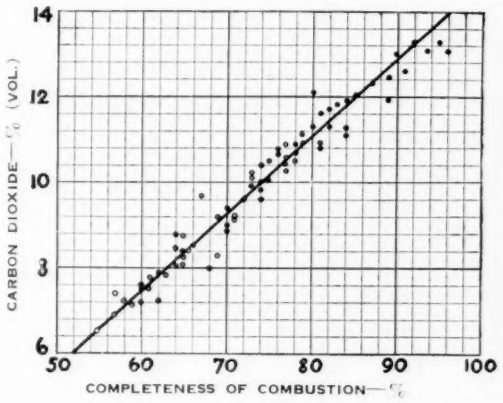


Fig. 1

inefficient many of the vehicles are, the average making use of only 75% of the fuel used. A little intelligent attention to the carburetor adjustment with the aid of such analyses would have made possible an average combustion efficiency of 85%-90% without sacrificing the performance of the vehicle, which is proved by the fact that several of the vehicles tested showed over 90% efficiency. Contrast this with the equal number showing less than 60%.

Heat Loss from Incomplete Combustion

Incomplete combustion does not necessarily mean that some of the liquid fuel passes through the engine without being burned. If the supply of oxygen is insufficient during combustion, the chemical reaction which takes place will be altered, and the total heat liberated to do work will be reduced. By complete combustion is meant the conversion of all carbon in the fuel to carbon dioxide. With an over-rich fuel mixture (which is synonymous to one having insufficient oxygen), some of the carbon will be burned to carbon monoxide, realizing only 30% of the heat possible from complete combustion. Carbon monoxide is a deadly poisonous gas in contrast to carbon dioxide which in itself is not at all poisonous. When a vehicle is run within the confines of a poorly ventilated garage the carbon monoxide becomes a menace and may easily reach such a concentration as to overcome anyone present. Dr. Yandell Henderson has shown that the maximum allowable concen-

*Serial No. 2225—March, 1921.

tration for an exposure of one hour, is only 0.04%. It was primarily to determine the amount of this poisonous gas given off by average vehicles, and the resulting necessary ventilation of the 8500 foot Vehicular Tunnels under the Hudson River, that these tests of the Bureau of Mines were undertaken. In Fig. 2

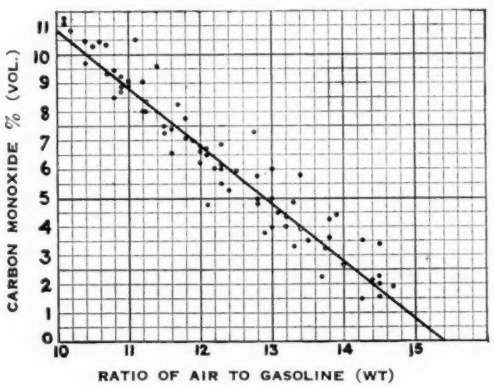


Fig. 2

is shown the variation of the percentage of carbon monoxide found in the exhaust of a large number of different vehicles, and the mixture proportions which were found. Notice that the carbon monoxide would be zero from a mixture having only a little more than 15 parts (by weight) of air to one of gasoline. This would correspond, as seen from Fig. 3, to the mixture giving maximum efficiency.

Reason of Over-Rich Mixtures

The question naturally arises: why are the average motor vehicles operated with such excessively rich mixtures? Fig. 3 shows one of the reasons—the carburetor adjustment giving maximum efficiency is not the same as that which gives maximum power. The latter requires burning about 25% more fuel per mile than the former.

Drivers often desire above everything else, a quick "getaway" with a cold engine, and speed. They thus set their carburetors as nearly as they can guess for maximum power with a cold engine. The accuracy of their guesses is shown when the power curve of Fig. 3 is examined between the air mixture limits of Fig. 2.

It will be seen that there are almost as many vehicles which lose power from excessively rich mixtures as from lean mixtures, and the amount of power lost in either case is not very great though the resulting thermal efficiency for the latter is nearly twice as great as for the former.

Table I shows how sensitive a typical carburetor is to small changes in adjustment, the

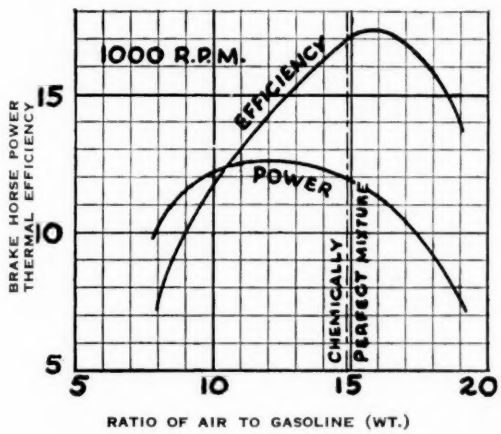


Fig. 3

difference of three-quarters of a turn of the needle valve reducing the mileage on a gallon of fuel over 40%.

TABLE I

Carburetor Adjustment. Needle Valve Turns.	Miles per Gallon of Gasoline	Exhaust Gas		Remarks
		% Carbon Dioxide	% Carbon Monoxide	
1	14.9	13.4	1.2	Exhaust clear; mixture too lean to operate without use of choke
1¼	13.9	12.0	2.0	Exhaust clear; operation satisfactory
1½	10.6	10.2	6.4	Exhaust slightly smoky; operation satisfactory; good acceleration
1¾	8.8	6.5	11.6	Smoky exhaust; too rich for satisfactory operation

As might be expected, the difference in mileage per gallon of fuel, between cars tested of the same make ranged from 36% to 100%, due principally to difference in carburetor settings.

Another reason for the use of extravagantly rich mixtures is the difficulty of completely vaporizing present day gasoline in engines designed during the days of more volatile fuels. This is a matter which requires some form of temporarily rich mixture while starting a cold engine, such as the use of a choke—and drivers

who do not realize the results of such negligence sometimes forget to open the choke after warming up. At this point a word about the present grade of gasoline will not be out of place.

Production vs. Volatility of Gasoline

During the last 11 years the production of gasoline in the United States has increased over 8-fold. This increase is far greater than the increased production of crude petroleum used by the refiners, which during the same time has increased barely 2½ fold. In other words, refiners have to produce more than 2½ times as much gasoline from a barrel of crude in order to keep up with the demands of motor vehicles, which increased about 30-fold in the same period. This increase has been made possible to some extent by the use of the so-called cracking processes, but primarily by including some of the products which were originally the most volatile portions of kerosene. This does not mean that present day gasoline "contains kerosene"; a mixture of kerosene and "high-test" gasoline has entirely different characteristics. It does mean, however, that the gasoline is not as volatile as previously. This lowered volatility is, of course, but small sacrifice to pay for the increased volume of gasoline which it has made possible, for the number of gasoline-using vehicles has been and still is increasing so much faster than the quantity of crude petroleum that it is the only possible way the demand for fuel can be met.

An examination of the volatility of a typical present day gasoline was made recently in the Research Laboratory of Applied Chemistry of M. I. T. Some of the results are shown graphically in Fig. 4, which gives the theoretical percentage of the gasoline mixture from the carburetor which can be vaporized at various temperatures, provided the mechanical conditions of atomization and manifold design are correct. There are many vehicle engines in use today which were designed in the days when gasoline was so volatile that any type of manifold or carburetor would serve. In such cases higher temperatures are required in order to secure the same degree of vaporization indicated by the curve of Fig. 4, because the mixture passes through the manifold at such a high velocity that it has little time for the heat to act on the liquid drops. The curve in reality shows limiting values which may be secured only with perfect mechanical design of the intake system.

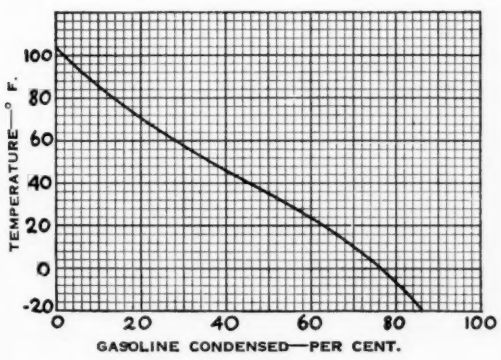


Fig. 4

Under these conditions, it can be seen that the gasoline vapor temperature in the manifold need be only 105° F. to be completely dry. Under the same conditions kerosene would require a temperature of about 240° F., while a fuel which might represent a future day gasoline with so much more of the parts of low volatility as to result in 25% more gasoline from a barrel of crude than is now secured, would require no more than 140° F. As this is a temperature easily and frequently attained in intake manifolds, it can be seen that there should be no theoretical difficulty in vaporizing modern gasoline after the engine has once been warmed up, provided a suitable manifold is used with a carburetor giving proper atomization.

Unvaporized Fuel in the Engine

But what happens before the engine is warmed up? In the first place, from Fig. 4 it can be seen that at 35° F., for instance, only one-half of the gasoline can be vaporized. This means that in order to start, some means must be provided to supply a large excess of gasoline to the cylinders. Usually this is accomplished by means of a "choke"—and sometimes by means of priming. It is also seen from this curve that starting is possible at less than even 15° below zero F., provided sufficient excess fuel is present to supply a combustible mixture from the small percentage that is volatile at such temperatures.

In the second place, the unvaporized liquid fuel is carried into the cylinders where it starts

trouble. Proof of the presence of this liquid was shown recently by an experiment where bottles were attached to an intake manifold, so that the liquid reaching the extremities would drain into the bottles. A section of this manifold is shown in Fig. 5. It was found that in

Courtesy of S. A. E. Journal

Fig. 5

Section of an intake manifold of a six-cylinder automobile engine, showing location of bottles which collected unvaporized fuel. The two center openings are exhaust ports, the hot wall below them being a typical "hot spot" for vaporizing the incoming fuel thrown against it.

starting the engine at 32° F, over two ounces of liquid were collected, which continued to increase slowly during operation, even after warming up unless a suitable manifold was provided. The condensate had a gravity of 46° Baumé while the gravity of the gasoline used was 68°. For any one class of fuel the gravity is an excellent indication of its volatility. The higher the Baumé gravity the greater the volatility, as is well known. Precautions should be taken, however, in using this rule for comparing fuels from different classes of crudes. For example a 54° California gasoline would have the same volatility as one of 64° from Pennsylvania, or 60° from Oklahoma.*

Carbon Deposits

The first part of this article pointed out the great, needless waste resulting from operating vehicles without carefully set carburetors, but when conditions are such that liquid fuel reaches the cylinders the ill effects are still greater because of the slow, but none the less certain, damage which can result to the car. Liquid fuel in the cylinders has two pronounced ill effects; one is the carbon formed when the heat of combustion "cracks" the liquid; the other is the effect on the lubricating oil. The presence of carbon is usually charged to the lubricant used. There is, of course, a great difference between some oils as to the carbon deposits they leave in the combustion chamber, but a wet, and particularly an excessively rich mixture will produce more carbon than any lubricating oil. Evidence of this is the black smoke thrown from the exhaust of any vehicle when the carburetor is given an excessively rich mixture.

Diluted Lubricating Oil

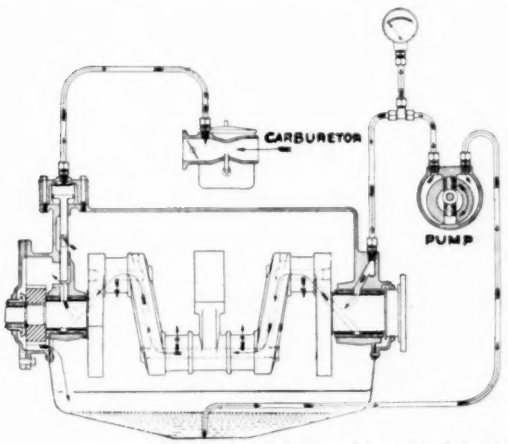
The most serious of all ill effects, however, is the action of the liquid fuel on the lubricant. The mixture rushes through the inlet valve over a mile a minute, with such a turbulent, swirling motion that there is ample centrifugal force to throw any liquid drops outward to the cylinder walls. There they quickly dissolve in the thin film of lubricating oil, and so lower its viscosity that the leakage of gases and diluted oil past the pistons during the combustion stroke is much increased. In this way a quantity of the unvaporized fuel accumulates in the lubricating oil in the crank case, with effects which are well known, examples of which were illustrated in the March issue of LUBRICATION. It is true that some lubricating oils lose their viscosity more rapidly when diluted with a little fuel than others, and thus the effects just mentioned may be accelerated or retarded by using one oil or another on those cars where the mechanical conditions are such that operation with a dry mixture is impossible.

From what has been shown in this article it should be clear that the first place to look for any trouble from excessive fuel consumption, carbon deposits, and diluted lubricating oil, is the fuel mixture. Hence the carburetor should always be set as *lean* as will result in good operation. Even if the running mixture is satisfactorily lean, an operator may prime his engine excessively or leave the carburetor choked after the engine has started. There is much room for mechanical development which will make the most economical fuel mixture "fool-proof," but until that time intelligent and continual care is necessary if the largest possible economy of fuel, lubricant and repair bills is to be attained.

*Bureau of Mines Bulletin No. 191—1920—p. 47.

Flow of Oil Through Bearings

THE modern tendency of machine design is toward higher and higher speeds of all parts, principally in order to get more production from a given financial investment. Simultaneous with this tendency has been the increasing use of circulating pressure feed lubricating systems for bearings. Which one is the cause of the other, and which the effect is not to be settled here, but without this type of lubrication many important high speed money-making machines now in daily use would be impracticable. There are three noteworthy advantages accruing from this system of lubrication when properly designed; (1) the metal surfaces are completely separated during operation by a film of oil of measurable thickness; (2) this results in a very low bearing friction and in negligible wear if solid matter is kept out of the oil system, and finally, (3) the heat of friction is carried away at a definite rate by the oil passing through the bearing so that the bearing and oil temperatures are under control. This latter is one of the most important factors involved in the successful operation of high speed machinery.



Courtesy of Automotive Industries

Fig. 1

Diagramatic Improved Circulating Pressure Lubricating System for Internal Combustion Engines

There is, however, but little data available to assist the designer of bearings lubricated by circulating pressure systems, except the experience gained from other similar bearings. As knowledge of the leakage and the flow of oil from bearings into hollow crankshafts was needed for the design of airplane engines during the War, an apparatus was constructed in order to obtain this data by the Airplane Engineering Division of the War Department, at McCook Field. The tests were not as comprehensive as could be desired, but the information collected is of value in many places, and is very suggestive of further research.

Apparatus Used

The apparatus used consisted of a $2\frac{5}{8}''$ diameter bearing $4\frac{1}{2}''$ long, of the ordinary construction used for Liberty Airplane Engines, supported in a special water jacketed casting so that the temperature of the bearing could be controlled. Oil was supplied from a 30-gallon tank under air pressure, which could be varied from 20 to 100 lbs. per square inch. The oil pipe from this tank was surrounded for a part of its length with a steam coil, which was used to heat the oil and maintain an oil temperature of 130° F. throughout the test. At this temperature the oil used had a viscosity of about 340″ Saybolt (63 cp absolute). An oil inlet was located one-third the length of the bearing from one end, so that the oil would have to flow twice as far to one end of the bearing as to the other, and the effect of bearing length could thus be determined. Provision was, of course, made for collecting the oil "leakage" from each end and for conducting it to measuring tanks.

Two shafts were used in these leakage experiments, one with a clearance of from 5 to 15 ten-thousandths, representing a tightly set bearing, and the other with a clearance of 20 to 40 ten-thousandths, representing a bearing worn to such an extent that it would be due for an overhaul. The shafts while being tested were driven at various speeds from 250 to 2,000 r.p.m. by a direct connected electric motor, so that there was practically no side thrust on the bearing.

It is much to be regretted that data concerning the frictional resistance that existed was not given, but this can be calculated approx-

imately.* With the friction known, and since the specific heat of oils is about 0.4 to 0.5, it is a simple matter to calculate the maximum temperature of the bearing, assuming that all the heat of friction is carried off by the oil. In reality quite a large amount is radiated from most bearings, but there is an increasing use of high speed bearings where radiation carries off only a small proportion of the heat. In these cases the quantity of oil necessary to hold the limiting temperature of the bearing to a definite figure, is given by the following formula:

$$\left\{\begin{matrix}\text{Quantity of Oil;}\\ \text{lbs. per hour}\end{matrix}\right\} = \frac{5500 \times \left\{\begin{matrix}\text{Friction H. P.}\\ \text{of bearing}\end{matrix}\right\}}{\left\{\begin{matrix}\text{Limiting bearing}\\ \text{temperature °F}\end{matrix}\right\} - \left\{\begin{matrix}\text{Temperature of oil}\\ \text{entering bearing}\end{matrix}\right\}}$$

In large steam turbine and similar bearings the circulation of the oil through the bearing is definitely controlled by oil inlets and outlets, both near the center. On the other hand the circulation through many small turbine bearings and all airplane and automobile engine bearings lubricated by the circulating-pressure system, is accomplished only by the leakage of oil out at the ends due to the oil pressure. This leakage is sometimes so great that an excessive amount of oil is sprayed into the cylinders and causes spark plug and other troubles. An interesting system which overcomes this trouble has been developed by Mr. Brush, and is used on several well-known automobile engines. As can be seen in Fig. 1, circulation is provided for all the excess oil which does not leak out of the bearings, through the hollow crankshaft from one end to the other. The by-pass valve regulating the oil pressure (which is controlled by the suction of the intake manifold) is located at the further end of the shaft. Thus a cooling effect can be secured much greater than from the leakage of oil past the bearing. In this connection it is interesting to recall the report that water was circulated through the crankshaft of the 240 H. P. Mercedes Engine originally used in Zeppelins.†

Data Secured

Some of the data secured at McCook Field on the leakage of oil from bearings is shown in Fig. 2, which gives the leakage of oil at the end of the bearing 3″ from the oil hole. The results are quite erratic, though they indicate that:

The leakage:

1. Increases with r. p. m.
2. Increases with oil pressure.
3. Decreases with bearing length.
4. Is not materially affected by clearance.

Item 1 was hardly to be expected and is of great interest, though Item 4 is so inexplicable that it should be looked upon with doubt until checked by further experiments.

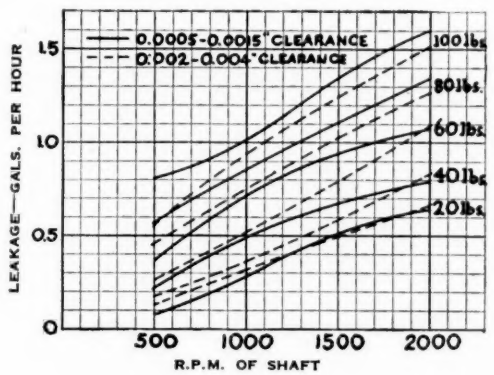


Fig. 2

Another series of experiments was run with this apparatus to determine the flow of oil from various sized oil holes in the bearing, through corresponding holes in the side of the shaft, and thus into the 1¼″ hole drilled axially to represent a hollow crankshaft. Under these conditions the flow of oil is intermittent, occurring only during the interval that the oil hole in the bearing registers with the corresponding radial hole in the side of the shaft. This series of experiments was divided into three groups:

1. The *pressure* was recorded at the center of the shaft by means of a connection to a pressure gauge from a plate bolted across the open end of the bearing, there being no flow of oil through the bearing except that caused by axial leakage.

2. The *quantity* of oil was measured which flowed from the center of the shaft through

* LUBRICATION—July, 1920, p. 3 (out of print).

[When bearing and shaft are concentric:]

Torque of fluid friction in foot pounds =

$$\frac{\left\{\begin{matrix}\text{Absolute viscosity}\\ \text{in centipoises}\end{matrix}\right\} \times \left\{\begin{matrix}\text{Shaft diam-}\\ \text{eter in in.}\end{matrix}\right\}^3 \times \left\{\begin{matrix}\text{Bearing length}\\ \text{in inches}\end{matrix}\right\} \times \text{R. P. M.}}{505{,}000{,}000 \times \left\{\begin{matrix}\text{Clearance on}\\ \text{diameter in inches}\end{matrix}\right\}}$$

† "Airplane Engines" by Neil MacCoull; S.A.E. transactions 1915, p. 168.

the opening in the center of the end plate for the oil pressure gauge connection just mentioned.

3. The *quantity* of oil was measured which flowed through the shaft when the oil outlet consisted of a second radial hole in the shaft, registering with a corresponding hole in the same bearing.

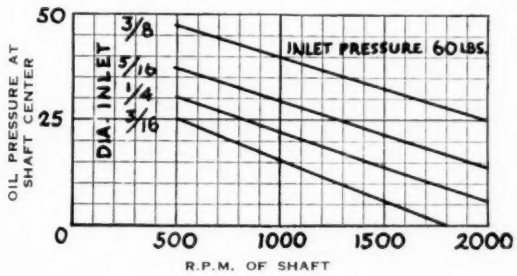


Fig. 3

The data of Group 1, shown in Fig. 3 reveals the interesting and unsuspected fact that the pressure at the center of the shaft decreases with speed. This might account for some of the lubricating troubles experienced with racing and other high speed engines, where the supply of oil to the connecting-rods and pistons was evidently reduced at high speeds when it was needed most. If there had been a groove around either the bearing or the shaft, so that the flow could have been continuous rather than intermittent, the effect of changing r.p.m. would have been a different story. In this test the pressure at the center of the shaft increased with increase in diameter of the oil hole; as well as increase of oil pump pressure. From Fig. 4 it will be seen that the pressure at the center of the shaft is approximately proportional to the product of the inlet pressure and the *diameter* of the oil hole.

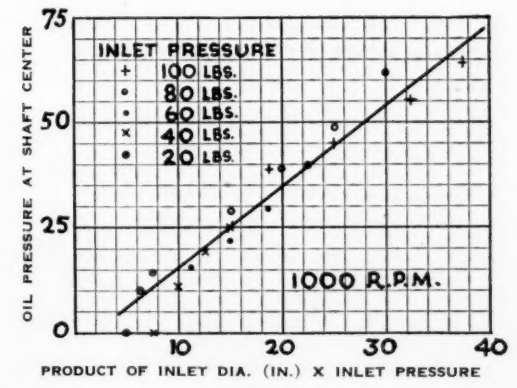


Fig. 4

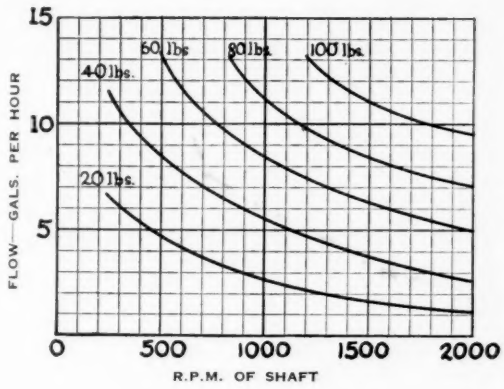


Fig. 5

Group 2 results are shown in Fig. 5 and 6, the former showing, for a $\frac{5}{16}$" oil hole, the reduction of flow with increasing r.p.m. which would be expected from the data of Fig. 3.

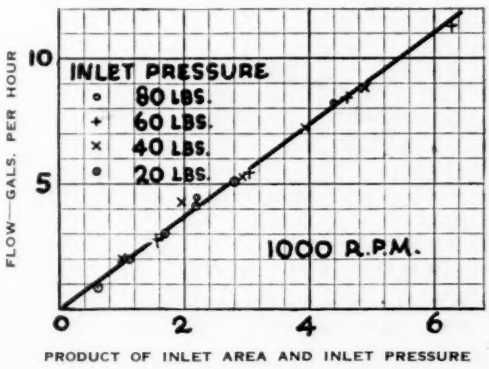


Fig. 6

Fig. 6 shows that at a given r.p.m. the flow is proportional to the product of the inlet pressure and the *area* of the oil hole.

Fig. 7 shows the group 3 results, i.e., the flow into one set of $\frac{5}{16}$" radial holes drilled

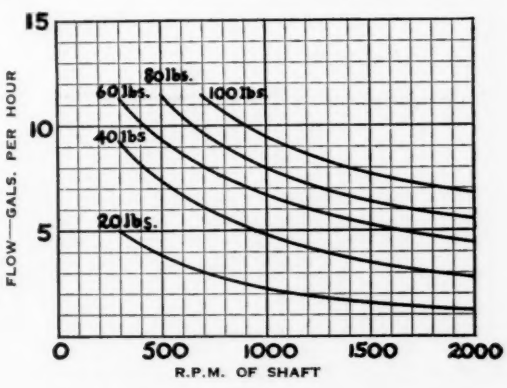


Fig. 7

through the shaft and bearing, and out of another similar set. This should be compared with Fig. 5, for if the reduction of flow with increasing speed in Fig. 5 were due to centrifugal force, the flow shown in Fig 7 should be greater than in Fig. 5 since in this test the centrifugal forces of the oil inlet and outlet would neutralize each other. The fact that the flow is less proves that centrifugal force has practically nothing to do with it.

Summary

Leakage

1. The axial leakage along a bearing from the center to the ends increases with the speed.

2. The amount of clearance of the shaft in the bearing has little effect on the amount of leakage.

3. The amount of leakage varies inversely as the distance of the oil inlet from the end of the bearing.

4. The amount of leakage varies directly with the inlet pressure.

Pressure

5. Where the oil is forced into a hollow shaft through a side inlet and a radial hole in the shaft wall, the pressure in the center of the shaft varies with the inlet pressure, and also with the *diameter* of the inlet hole, but decreases as the speed is increased.*

Quantity

6. The quantity of oil forced into a bearing* through a side inlet and into the hollow center of the shaft varies directly as the product of the inlet pressure and the inlet area, instead of the diameter as in the case of pressure (Item 5), but decreases as the speed is increased.

7. Where the oil is forced through a side inlet to the bearing and through a radial hole to the center of the shaft, and then out through another radial hole and a corresponding side outlet from the bearing, the quantity passing through the bearing and shaft depends more on the size of the inlet than that of the outlet.

Conclusion

These tests were run for the sole purpose of obtaining data and for developing formulas which would be useful in design work, where lubrication is accomplished by a circulating pressure oiling system feeding oil intermittently into a hollow crankshaft such as is used in airplane and other automotive engines, as well as small steam turbines and many other high speed machines. The data secured should be useful to designers in correcting existing faults in lubricating systems, and as a basis of calculations for new designs. If a condition exists where an over-quantity of oil is fed to a bearing and the pressure is still as low as possible, the necessary corrections may be determined from the results of these tests. The same may be said when the pressure is high and the quantity of oil reaching any part of the system is low.

Where the conditions of crankpin oiling are to be studied it is necessary to add to the internal pressure in the hollow center of the crankshaft the centrifugal force caused by the rotation of the oil in the crankcheek and the crankpin. With this data a positive step has been taken in the direction of predicting the conditions of oil flow in crankpin bearings and also main bearings lubricated by a circulating pressure system. It is hoped that similar experiments of a more comprehensive nature will be available for engineers in the near future to supplement this very suggestive preliminary work.

* The experiments were confined to *intermittent* flow only.

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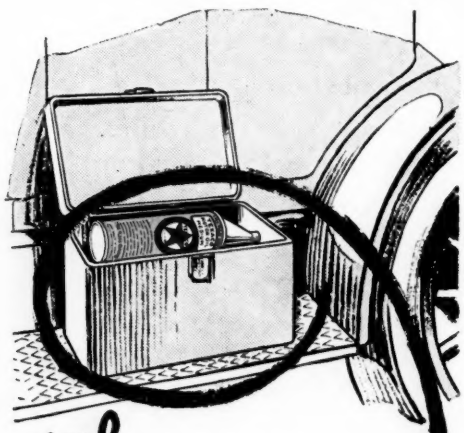

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